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# Evaluation Of A Human Modelling Software Tool In The Prediction Of ExtraVehicular Activity Tasks For An International Space Station Assembly Mission.

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## ABSTRACT

The difficulty of accomplishing work in extravehicular activity (EVA) is well documented. It arises as a result of motion constraints imposed by a pressurized spacesuit in a near-vacuum and of the frictionless environment induced in microgravity. The appropriate placement of foot restraints is crucial to ensuring that astronauts can remove and drive bolts, mate and demate connectors, and actuate levers. The location on structural members of the foot restraint sockets, to which the portable foot restraint is attached, must provide for an orientation of the restraint that affords the astronaut adequate visual and reach envelopes. Previously, the initial location of these sockets was dependent upon the experienced designer's ability to estimate placement. The design was tested in a simulated zero-gravity environment; spacesuited astronauts performed the tasks with mockups while submerged in water. Crew evaluation of the tasks based on these designs often indicated the bolt or other structure to which force needed to be applied was not within an acceptable work envelope, resulting in redesign. The development of improved methods for location of crew aids prior to testing would result in savings to the design effort for EVA hardware. Such an effort to streamline EVA design is especially relevant to International Space Station construction and maintenance. Assembly operations alone are expected to require in excess of four hundred hours of EVA. Thus, techniques which conserve design resources for assembly missions can have significant impact. We describe an effort to implement a human modelling application in the design effort for an International Space Station Assembly Mission. On Assembly Flight 6A, the Canadian-built Space Station Remote Manipulator System will be delivered to the U.S. Laboratory. It will be released from its launch restraints by astronauts in EVA. The design of the placement of foot restraint sockets was carried out using the human model Jack, and the modelling results were compared with actual underwater test results. The predicted locations of the sockets was found to be acceptable for 94% of the tasks attempted by the astronauts. This effort provides confidence in the capabilities of this package to accurately model tasks. It therefore increases assurance that the tool may be used early in the design process..

## INTRODUCTION

The National Aeronautics and Space Administration has a long history of application of rigorous methodology to systems engineering. The approach extends back to the very beginning of the von Braun era and thus predates the wide adoption of design principles that have since been applied in, for example, computer systems (*cf.* Gould and Lewis, 1985). The principles can be summarized as: a) an early focus on the requirements of the system, b) testing to ensure the system meets the requirements, and c) iterative design. In the case of human-occupied and operated space hardware, the requirements include a focus on the needs of the user. The system must support or be operable by the astronaut. Otherwise, the other system components will be of little value, however well designed. One of von Braun's contributions to the empirical phase of design of human space systems is the introduction of underwater testing to NASA at the Marshall Space Flight Center. This test facility, known as the Neutral Buoyancy Simulator, and others like it are used to provide a frictionless environment in which engineers and astronauts can assess design effectiveness. Mockups of the hardware are submerged and outfitted with flotation to make them neutrally buoyant; *i.e.*, they neither sink nor float, but tend to retain their position, as an object would in space. The test subject, likewise deprived of friction, is able to evaluate whether useful work (e.g., bolt drive, connector mate and demate, and lever actuation) can be accomplished with the system. This type of testing is especially useful for ExtraVehicular Activity (EVA) hardware. The motion constraints imposed by a pressurized spacesuit in a near-vacuum are difficult to simulate outside of the underwater environment, due to the weight of the suit. These constraints, along with the effects of suit bulk, must be incorporated in the testing to ensure the design compensates for them.

Construction of the International Space Station is expected to require in excess of four hundred hours of EVA. Neutral buoyancy testing, while effective when properly integrated with the other design principles, is expensive. The cost of testing all of the designs which must support this EVA is a significant part of the design budget. Methods which allow the proper implementation of system design principles while reducing this cost would be of considerable value. In the last ten years, there has been a near-complete transition in the engineering design environment from two-dimensional drawings to three-dimensional Computer-Aided Design (CAD). The human factors personnel responsible for ensuring EVA designs are workable are thus afforded

new opportunities to examine the human/machine interfaces through computer simulation. Computer models allow more thorough insight into these interfaces than was previously possible with drawings. Several human modelling packages have been developed which allow simulation of the work tasks as they would be performed in space, the human figure is placed into position to interact with the CAD models of the hardware. However, validation of these modelling systems must be accomplished before their results can be accepted by designers. Only a few efforts have been made to compare the computer simulation results with real-life human/machine interaction. Since the simulation mimics the test, as well as the space environment, neutral buoyancy testing provides the opportunity to examine the results of computer modelling. This paper will examine the utility of a human modelling software application in the examination of tasks associated with an International Space Station EVA design. The work has two components: a modelling effort and a comparison between the predictions from modelling and the results of neutral buoyancy evaluation of the tasks.

**The design effort** for which the human factors engineer is primarily responsible in EVA-operated hardware is the reduction of the effects of microgravity. Useful work is essentially impossible for a free-floating astronaut. One solution to this problem developed by NASA is to secure the astronaut on a platform called a foot restraint. The astronaut slides his or her boots into loops on a foot restraint (see Figure 1), securing them to the plate of the restraint. A foot restraint thus provides anchorage against which to react the forces required to release or tighten bolts and perform other tasks. The appropriate placement of foot restraints is critical to accomplishment of EVA work tasks, and it is this placement which comprises a significant portion of the human factors engineer's contribution to the design. This placement of the restraints is also a useful metric for the validation of the human modelling packages. The bulk of the modelling effort in this first attempt to assess the efficacy of the software consisted of positioning the restraints on the hardware. The foot restraint positions thus predicted were tested in the Neutral Buoyancy Simulator by astronauts and engineers who determined whether the work they were required to perform was is feasible. These evaluations provided the data for determining the effectiveness of the modelling.

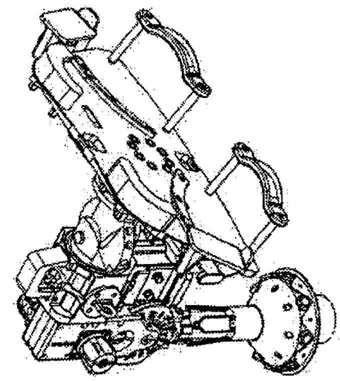

**Figure 1.** International Space Station type foot restraint. The astronaut places boot toes into the straps on the platform and hooks heels under the ledges on the left side of the drawing (the back of the platform). The joints in the support structure allow many different configurations.

**The International Space Station Assembly sequence** consists of a series of more than forty hardware launches on Russian and American vehicles, the latter being the U.S. National Space Transportation System, or Space Shuttle. Assembly from components will be achieved through a combination of robotic manipulation and EVA. Robotics will be conducted initially by the Shuttle's robotic arm, the Remote Manipulator System. After the Station becomes habitable, another Canadian-built arm, the Space Station Remote Manipulator System (SSRMS), will be delivered and will take over most Station robotic operations. Assembly Flight 6A, the sixth American launch, will carry the SSRMS and other cargo to the U.S. Laboratory module in January, 1998, The cargo will be attached to a U-shaped pallet which fits in the Shuttle Payload Bay. Marshall Space Flight Center is responsible for packaging the cargo in the pallet, and the design must allow the removal of the hardware by EVA. The astronauts will remove bolts, attach cable connectors, and operate mechanisms in the course of removing the cargo and deploying it to the Station. The majority of these tasks will require the use of appropriately located foot restraints.

## METHODS

The human modelling package, Jack, was developed by the University of Pennsylvania as an anthropometric human factors tool. The human model, also referred to as Jack, can be scaled to the standard anthropometric dimensions, allowing the user to develop models that simulate a wide variety of body forms. For these simulations, models for 5'", 50 'h, and 95 th percentile humans, by stature, were used, in accordance with NASA standards documentation (NASA, 1995) and published suit data (Pantermeuhl, 1995). Jack attaches kinematics features to any articulated figure. *Realistic joint motion limitations were* imposed on the models of the spacesuit, the foot restraint, and the robot. CAD models of the cargo were obtained from the designers: the Canadian Space Agency provided a model of the arm, models of additional pallet cargo came from McDonnell Douglas Aerospace and The Boeing Company, the spacesuit and foot restraint were from Johnson Space Center, and Marshall Space Flight Center supplied models of the pallet and the bracketry used to attach the cargo to it. Versions 5.8 and 5,9 of Jack were used in the simulations.

The spacesuited human figure was placed in the appropriate location with respect to the hardware to simulate the task. Reach and visual envelopes were examined, and measurements were taken where appropriate. Once task feasibility was ascertained, the foot restraint was attached to the model's feet and attach points on the pallet were determined. Further data were collected on the foot restraint joint angles, which were read from the software (Dischinger *et al.*, 1996).

After foot restraint attach points were determined, modelling simulations were conducted to attempt to accurately depict body positioning and reach that a spacesuited subject would assume in order to accomplish the tasks required for hardware removal.

An underwater evaluation was performed on mockups built to the design used and generated in the simulations. This test series was conducted at the Neutral Buoyancy Simulator. It consisted of evaluations of the design by eight engineers and astronauts, working in pairs. The subjects attempted the tasks working from foot restraints placed where the modelling simulations predicted they should be and using the joint configurations predicted by the simulations. The tasks were rated according to difficulty. The rating scale indicated whether the design was acceptable (the task could be done by a trained astronaut) or unacceptable, with *varying implications of the latter (minor* modification through complete redesign required). Still photographs were used for comparison with the results of the simulations for correspondence of outcome.

## RESULTS

The neutral buoyancy simulations indicated 96% of the tasks should be feasible for trained astronauts of the full range of anthopometric sizes; 94% of the foot restraint locations were rated as acceptable. The percentages of predicted foot restraint joint settings which were given acceptable ratings are shown in Table 1.

| **Configuration variable** | **Percent acceptable** |
|---|---|
| Orientation at attach point | 79 |
| Pitch | 59 |
| Roll | 78 |
| Yaw | 78 |

**Table 1. Percentage of foot restraint** *configuration settings predicted by modelling* that were found to be acceptable in test.

Body position models, when compared to photographs of astronauts performing the tasks, were found to be faithful to the real task execution, An example comparison is given in figure 2. In the model and in the actual photograph from the neutral buoyancy simulation, the two astronauts are depicted removing one of the pieces of hardware to be installed *on the Station called the Laboratory* Cradle Assembly (this structure has a grasping latch and will be used for temporary attachment of other hardware to the Station). A model of a fifth percentile woman was generated and used as the figure on the left in 2a. The actual astronaut who performed this task nearly fit this stature category, and the photograph (2b) indicates the modelling closely simulated her reach capabilities.

In *one* case, the attempt to place a foot restraint was unsuccessful; there was no available structure *to which it could be secured.* The task simulation suggested an operational solution to the problem. The task requires that one astronaut pass a long bolt which has been removed from the SSRMS to the other astronaut, who would stow it in a safe place. The only available structure to which the foot

restraint for the second astronaut might be attached put even the largest astronaut out of reach of the hand-off. Based on the modeling results, it was recommended that the recipient be in free float; *i.e.*, tethered to prevent separation from the Station, but not attached to a restraint. When the task was attempted this way in the Neutral Buoyancy Simulator, free-float was found to be an appropriate solution.

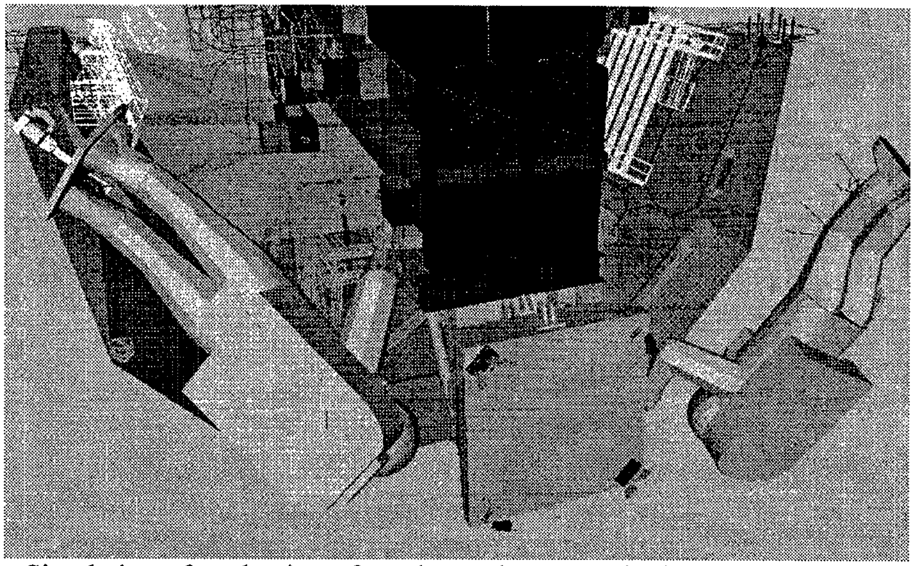

Figure 2a. Simulation of evaluation of reach envelopes required to release cargo from the pallet. The spacesuited model on the left is in a foot restraint attached to the upper left portion of the pallet; she is shown reaching hardware interfaces from this attach point.

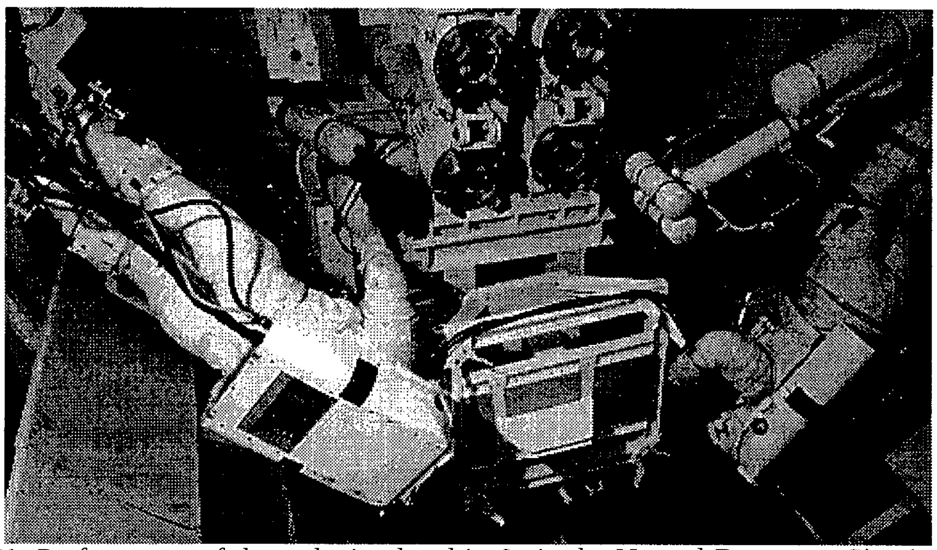

Figure 2b. Performance of the task simulated in 2a in the Neutral Buoyancy Simulator; the task was rated acceptable by astronaut and engineer evaluators, The foot restraint was properly placed, and the body envelopes of the spacesuited figure were appropriate.

DISCUSSION

Jack was found to accurately predict task feasibility for 94 percent of the tasks. It must be noted that this reliability occurred despite considerably lower accuracy in predicting the foot restraint joint settings. These were found (Table 1) to be as low as 59 percent reliable. That is, the suited subjects in the Neutral Buoyancy Simulator found that tasks could be accomplished from the foot restraint placement that had been predicted, but they preferred different orientations. This conflicts slightly with the modelling exercise depicted in Figure 2, which shows concordance

between human figure models and their real test subject counterparts. This demonstrates a limitation of the modelling system, but it is not yet understood which limitations are inherent to Jack and which result from constraints derived from standards documentation. It is clear that at this point, Jack (like other known human models) is incapable of simulating many fine motor tasks. For example, the connectors used in EVA mating of power and data lines are cylinders with bales (levers which engage the two connectors to be joined, pulling them together) on the sides. The EVA astronaut grasps the cylinder along its length and actuates the bale with the thumb, the way one would turn on or off a flashlight. While Jack has grasping capabilities, it cannot yet actuate the bale. Bale actuation is vital to cable connection, and it is thus insufficient to determine that the design provides access to connectors. This is because there are some positions at which one might be able to reach a connector but be unable to slide the bale due to strength or motion limitations. In addition, Jack does not "know" which body positions are comfortable for astronauts, and therefore no such information is available from the modelling. Astronauts, on the other hand, will reposition the foot restraints to compensate for motion limitations not part of the model or for comfort. For the current exercise, these limits on the model capability appear to matter little. Eventually, however, they will likely be accounted for. We are currently planning a neutral buoyancy test which we hope will give us some information about how important information about fine motor constraints is to modelling.

Jack was developed for applications at the earth's surface, Microgravity effects we have included so far are crude. Improvements we plan to attempt include a more realistic neutral body posture and suit-driven motion constraints. The neutral body posture is the somewhat crouched, "arms floating" posture assumed by people in space. The current motion constraints are derived from two- and three-dimensional records of motion studies of suited subjects, That is, they amount to pictures of what subjects are capable of in a suit. A more useful approach is to impose limitations on the suit that are derived from design and pressurization and then to allow the human figure inhabiting it to be so constrained. Heretofore, computational power has limited this capability. The time when this is feasible using workstations is foreseeable.

It should be noted this work does not "validate" Jack as an EVA modelling tool. There are not enough data to conduct statistical analyses on or to draw generalizations from. However, it should give some confidence that this software and other packages like it are of value in understanding gross EVA task design. More to the point, the replacement of neutral buoyancy testing of designs by modelling is not predicted in the near future. While incorporation of fine motor skill constraints is given as a goal, its realization is likely to be in the fairly distant future. A cursory examination of the many fine-tolerance tasks performed on a Hubble Space Telescope upgrade would give even the most enthusiastic modelling supporter pause. This is likewise true of many of the tasks required for Station assembly.

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